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Anomalous tremor before 2008 *M*s8.0 Wenchuan earthquake: a review

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Abstract: In this paper we give a review of several previously published papers on anomalous tremors observed before the 2008 *M*s8.0 Wenchuan earthquake. Based on the observed time and frequency shifts between coastal and inland stations, we discussed some methods to distinguish different kinds of microseisms, and speculated that a pre-earthquake typhoon might have caused a "mainland-originated microseism" which in turn triggered the earthquake.

Key words: *M*s8.0 Wenchuan earthquake; anomalous tremors before earthquake; review; microseisms; typhoon

1 Anomalous tremor before earthquakes

Having long been interested in the phenomenon of anomalous tremors before earthquakes[1], soon after the 2008, May 12 *M*s8.0 Wenchuan earthquake, we reported a pre-earthquake disturbance recorded by a Lacoste ET – 20 gravimeter in Wuhan[2], and suggested that "Anomalous Microseism" with a period of 4 – 8 seconds had occurred 48 hours before the earthquake (Fig. 1). Similar disturbances were recorded by broadband seismometers at Beijing, Enshi, and Mudanjiang seismostations[3], and other national seismic stations[4]. Pre-earthquake disturbances were later reported for the 2009, March 19 *M*w7.6 Tonga and 2010, January 12 Haiti earthquakes also[5,6].

2 Time and frequency shifts of anomalous pre-earthquake tremors

A strong typhoon Rammasun, however, had occurred over the West-Pacific shortly before the earthquake. Thus we need to check whether the recorded disturbances were caused by the typhoon or the earthquake. To accomplish this, we compared data recorded at both inner-land and coastal stations in China.

The anomalous tremors observed at seismic stations in coastal areas reached a maximum on May 11 (when the typhoon was nearest and strongest), one day before the earthquake, whereas at the inland stations the maximum amplitude occurred about 30 hours later on May 12, the day of the earthquake (Fig. 2). If the tremors recorded at inland stations were caused by typhoon also, they would have occurred no more than half hour later than those recorded at the coastal stations (transmitted by Rayleigh waves from the coast).

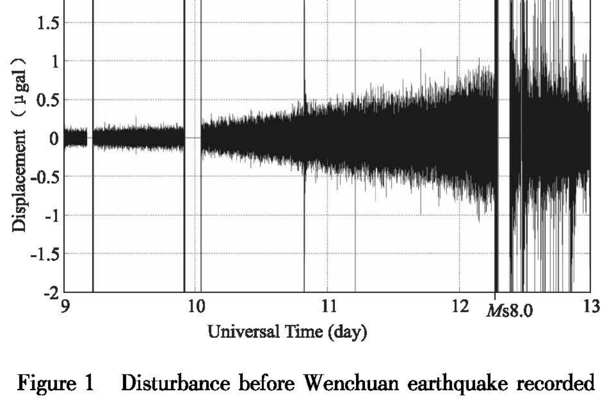

Figure 1 Disturbance before Wenchuan earthquake recorded by a Lacoste ET gravimeter at Wuhan seismostation

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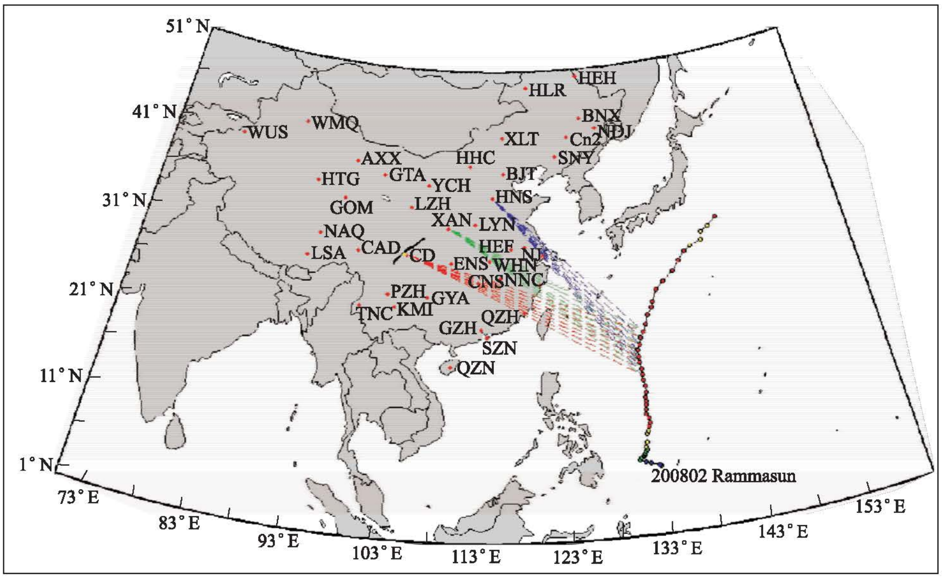
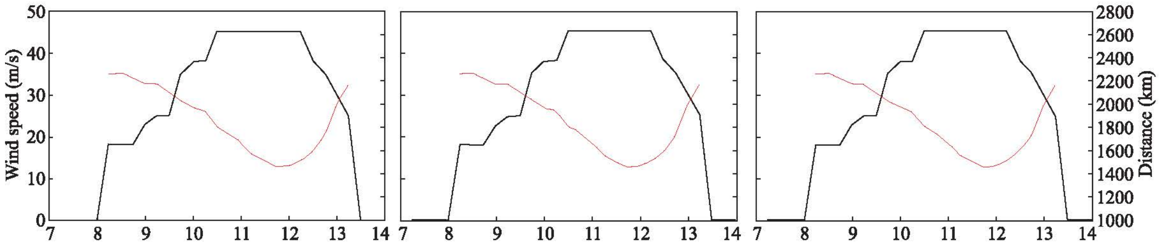
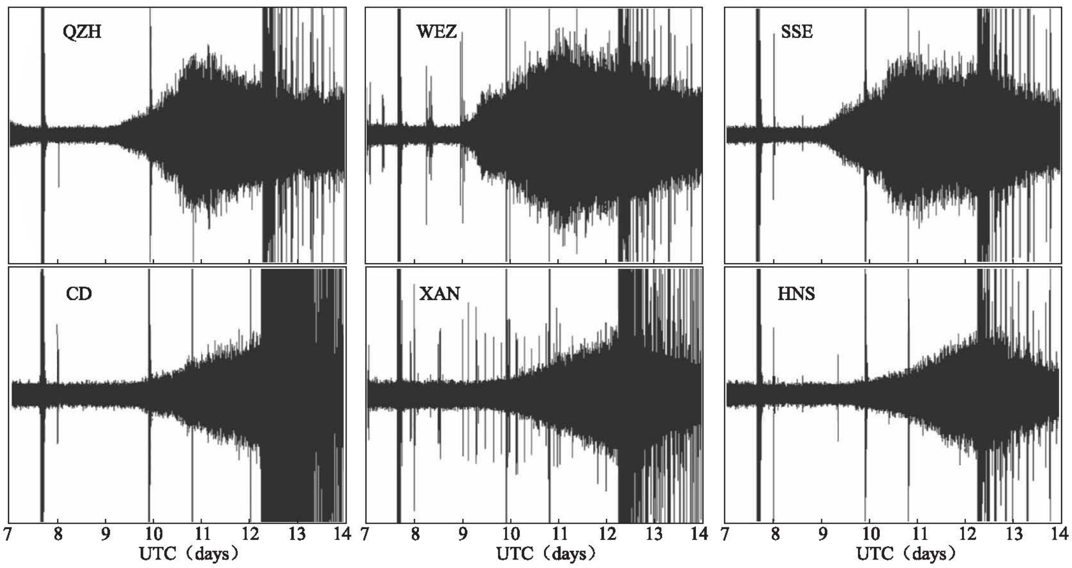


(a) The track of the typhoon Rammasun (connected dots). The red dashed lines indicate seismic wave propagation paths for station QZH close to station CD, and the green and blue lines for WEZ, XAN and SSE, HNS, respectively



(b) Wind-speed variation of Rammasun (black curve). The red curve shows distance between the eye of typhoon and station WEZ



(c) At near coast stations QZH, WEZ and SSE, anomalies before the great Wenchuan earthquake started on May 9, and the maximum amplitude appeared on May 11. At inland stations CD, XAN and HNS, the anomalies started on May 10, and the maximum amplitude appeared on May 12 when the great earthquake occurred

Figure 2 The anomalous tremors observed at seismostations

Similarly, before the *M*s8.1 Kunlun earthquake, a strong typhoon Lingling occurred over South China Sea, and an anomalous pre-earthquake tremor occurred at the same time. However, the anomalous tremor was not only stronger than the typhoon-related signal but also had a lower frequency. This frequency shift together with the above-mentioned time shift both suggest that the anomalous tremors recorded at the inland stations were not caused directly by typhoon[7,8].

3 Marine-originated and mainland-originated microseisms

By studying the above-mentioned shifts in time and frequency, hopefully we may better understand the mechanism of the anomalous tremors. For this purpose, we carefully analyzed the records at nearly 200 Chinese broadband-seismometer stations, both national and regional. Their time-frequency features indicated that the tremors consisted of two kinds of microseisms with distinctly different features[9].

For comparison, we show in figure 3 the results of two stations, one coastal and one inland. The 30 hour seismic records before the Wenchuan earthquake were divided into three 10 hour parts, and their PSD(Power Spectral Density) showed that at the coastal Quanzhou (QZH) station, the energy of the typhoon-induced microseism (0.2 – 0.25 Hz) had started to decrease since 30 hours before the earthquake. However, at the inland Chengdu (CD) station the energy of microseism (0.12 – 0.17 Hz) started to increases slowly at first, and then dramatically to a maximum 10 hours before the earthquake. The energy was much stronger than that of typhoon-induced microseism and does not change with travelling route and strength of the typhoon. Thus it must be a microseism not directly induced by typhoon.

As shown in the longer seismic records (Fig. 4), the typhoon induced (marine-originated) microseism is very strong at the coastal station QZH, whereas non-typhoon induced microseism is pronounced at the inland CD.

The 30-hour seismic records before the Wenchuan earthquake were divided into three equal parts, and PSD analysis was applied to each 10-hour part. The analysis show that at QZH the energy of typhoon-induced microseism (0.2 – 0.25 Hz) had decreased 30 hours before the earthquake, but at CD the energy of microseism (0.12 – 0.17 Hz) had increased, and reached a maximum value in the 10-hour time window just before the earthquake.

The 90-hour seismic records before the Wenchuan earthquake were divided into 90 equal parts. PSD transform is applied to each one-hour part and the hourly variable energy spectra were calculated in the band 0.12 – 0.17 Hz and 0.2 – 0.25 Hz, respectively. The energy change of microseism in 0.2 – 0.25 Hz (black dots) is considered to be related to typhoon Rammasun, whereas the energy change of microseism in 0.12 – 0.17 Hz (red) is considered to be not related to the typhoon. The latter started a dramatic increase 10 hours before the earthquake to its peak when the earthquake occurred.

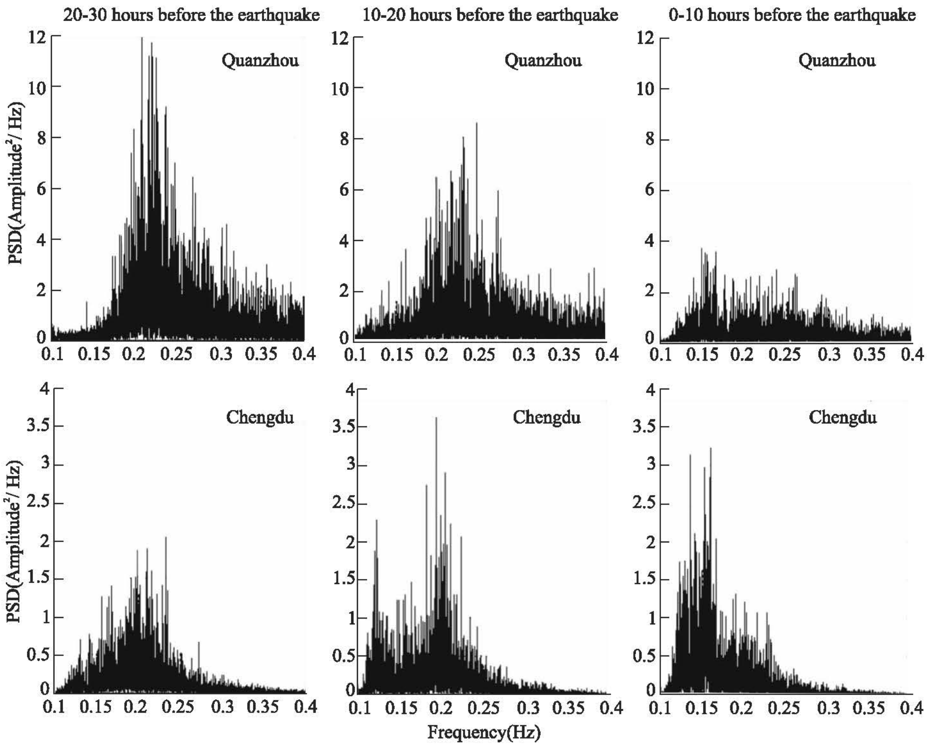


Figure 3 Results of PSD analysis of the seismic records from stations Chengdu and Quanzhou

4 Mechanism of microseism before a large earthquake

What was the origin of the microseism not directly induced by the typhoon? Microseism might be caused by ocean waves induced by typhoons, but it is remarkable that some of them were detected by seismometers on land several hours before the sea waves reached the coasts[10,12]. In 1950, Languet-Higgins suggested that this phenomenon was caused by nonlinear interference of ocean-wave vibrations[13]. The standing-wave theory was applied to the analysis of ocean-induced microseism, and was further developed by Hasselmann and Tanimoto[14,16]. Now we know that typhoon-induced ocean waves can produce two kinds of microseism: Firstly, the primary microseism in the frequency band of 0.05 – 0.1 Hz may be produced by surf against the land at the same frequency. It is relatively weak and may gradually disappear after spreading out a few kilometers inland. The second kind, the marine-generated microseism with frequency of 0.1 – 0.5 Hz band, is caused by the pressure of the standing waves on sea bottom. It is about one-hundred times stronger, and can spread more than ten thousand kilometers inland by Rayleigh waves at a speed of 3 km/s[17]. This is why some typhoon induced microseisms were detected by inland seismometers several hours before the sea waves reached the coasts.

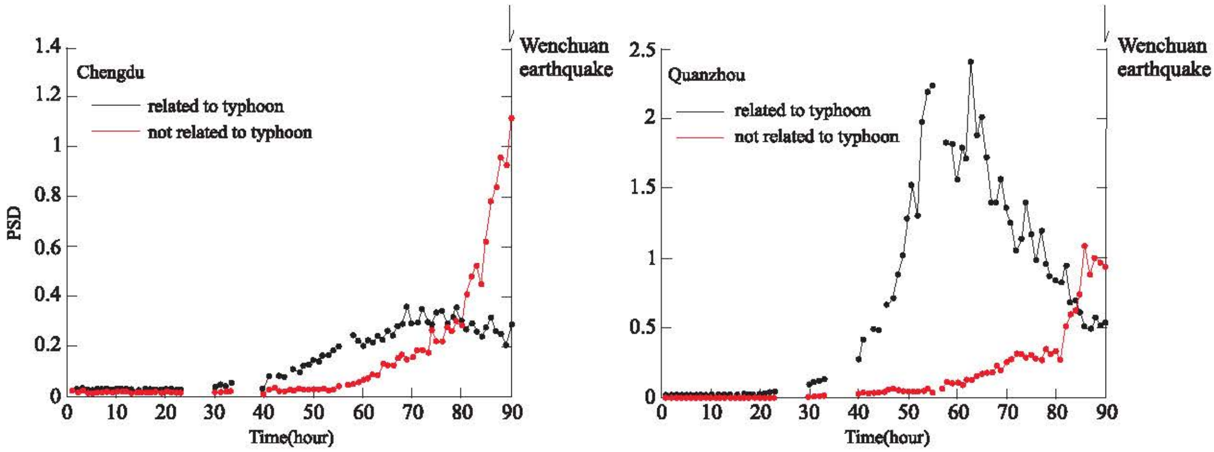


Figure 4 Results of PSD analysis of the 90-hour records at stations Chengdu and Quanzhou

However, for the above-mentioned microseism with time and frequency shifts observed before Wenchuan and Kunlun earthquakes, we need to find some other explanation. We speculated[17] that there was another kind of standing wave (mainland-originated microseism) formed when the typhoon-generated Rayleigh waves travel through a region with large faults under a certain suitable condition, and the pressure change of this kind of microseism may have triggered the earthquakes. Data recorded by the dense network of inland seismic stations in Sichuan (Fig. 5) may offer an opportunity to test this hypothesis.

5 Concluding remarks

We proposed a hypothesis that a strong typhoon may trigger a large earthquake[5]. The possibility that typhoon may trigger slow earthquakes was reported by a paper in Nature at about the same time as ours[18]. Also, a paper published later in Science reported the observation of slow-slip events at the base of the brittle crust for 44 minutes before the *M*w7.6 Izmit earthquake in Turkey[19]. Both of these findings may support indirectly our concept of mainland-originated microseism.

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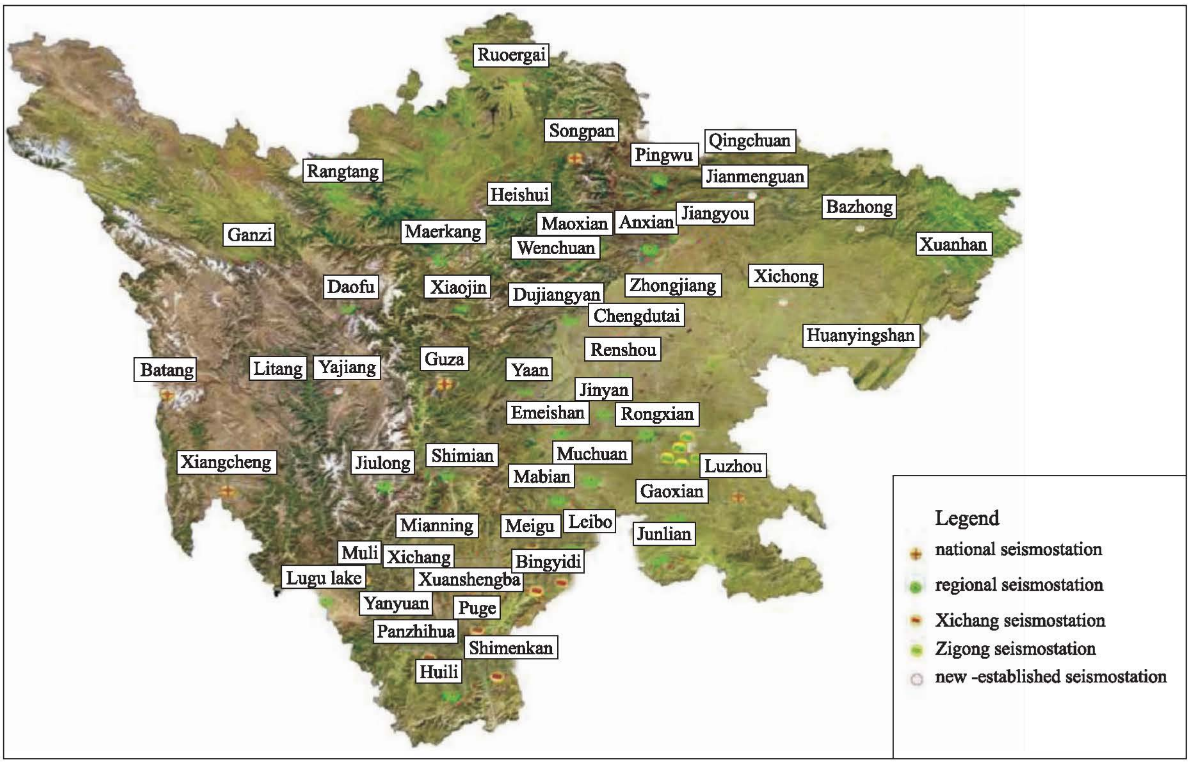

Figure 5 Distribution of digital-seismometer stations in Sichuan

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